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The operational amplifiers radiation hardness experimental study

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Abstract. The radiation hardness of the operational amplifiers IS-OU2 and LM358 has been performed experimentally using X-ray research complex. It was found that the measured characteristics of operational amplifiers (input offset voltage, consumption current, voltage gain) for the IS-OU2 and its analogue LM358 are similar and demonstrate radiation hardness. As a result, the designed and produced IS-OU2 operational amplifier can be used for producing of spacecraft equipment electronics that can operate under space radiation conditions.

Keywords: operational amplifiers, X-ray irradiation, ionizing dose effects

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Экспериментальное исследование радиационной стойкости операционных усилителей

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Аннотация. Радиационная стойкость операционных усилителей IS-OU2 и LM358 была исследована экспериментально с использованием рентгеновского исследовательского комплекса. Установлено, что измеренные характеристики операционных усилителей (входное напряжение смещения, потребляемый ток, коэффициента усиления напряжения) для IS-OU2 и его аналога LM358 схожи и демонстрируют радиационную стойкость. Спроектированный и изготовленный IS-OU2 операционный усилитель может быть использован для производства электроники бортовой аппаратуры космических аппаратов работающих в условиях космического излучения.

Ключевые слова: операционные усилители, рентгеновское излучение, эффекты поглощенной дозы

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Introduction

As it is well known, the operational amplifiers are important parts of modern electronics devices that are used widely in many industrial applications such as power engineering, energy systems, electrical engineering etc. [1]. For development of industries (cosmonautics, aircraft, engineering etc) it is necessary to achieve reliable functioning of the electronic components that used under radiation conditions such as space and nuclear radiations [2]. For instance, for similar type of bipolar operational amplifier (LM358) were established earlier its radiation hardness and some radiation-sensitive parameters to the total ionizing dose effects during its irradiation treatment [3]. Therefore, with taking into account, the main goal of this work is to study the radiation behavior features, define radiation-sensitive parameters and estimate radiation hardness to the effects of the total ionizing dose of designed operational amplifier IS-OU2 (analogue of LM358) using the developed X-ray research hardware and software complex (XRC).

Materials and Methods

The objects of the study were operational amplifier IS-OU2 (designed by Bryansk State Technical University) and then manufactured by JSC "GRUPPA KREMNY EL" [4]) and its analogue LM358 in the SO-8 type package. For radiation behavior study was used the developed XRC consisting of the following parts: X-ray equipment RIK-0401, X-ray comparator DRI-0401, a set of measuring equipment (sources-measuring instruments PXIe-4143, PXIe-4139), and the developed software. The developed XRC is described in detail earlier in [5, 6]. For operational amplifier microcircuit, the XRC allows monitoring the main characteristics (input offset voltage, consumption current, voltage gain, input offset current etc.). The radiation behavior study of operational amplifiers IS-OU2 and LM358 was performed the following operating mode of RIK-0401: anode voltage – 70 kV, anode current – 220 μA, the rate of radiation dose accumulation was 250 un./s (un. – units of the DRI-0401 comparator including in XRC), the distance between the X-ray tube window and the sample – 25 mm.

Results and Discussion

The operational amplifiers IS-OU2 and foreign analogue LM358 [7] during irradiation process were in the active electrical mode (at supply voltage ±16 V). During the study, the main radiation-sensitive parameters of the IS-OU2 have been established (V_{OS} – input offset voltage, I_C – consumption current, K_U – voltage gain). For instance, the dependencies of the input offset voltage V_{OS} at the minimum and maximum supply voltage on the total ionizing radiation dose D for samples of operational amplifier IS-OU2 and analogue LM358 are shown in Fig. 1, *a* and Fig. 1, *b*. As follows from Fig. 1, the input offset voltage at the minimum (Fig. 1, *a*) and maximum (Fig. 1, *b*) supply voltage for the developed operational amplifier IS-OU2 and the analogue LM358 increases very slightly with an increase in the total ionizing dose of radiation up to 600×10^3 un. It should be noted that input offset voltage is the radiation-sensitive parameter as was established earlier for similar operational amplifier LM358 in paper [3] during gamma irradiation treatment. Because of this input offset voltage values for developed amplifier IS-OU2 do not exceed maximum (±3.5 mV [4, 7]) and are comparable with LM358. Also it was found that the consumption current and voltage gain for the samples of the operational amplifiers IS-OU2 and its analogue LM358 are quite close.

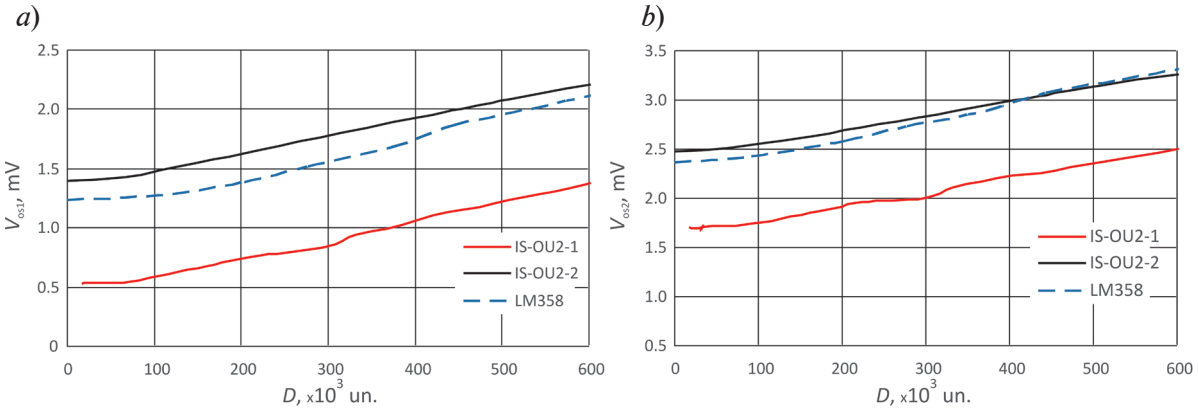

Fig. 1. Dependence of the input offset voltage V_{OS} at the minimum ± 1.5 V (*a*) and maximum ± 16 V (*b*) supply voltage on the total ionizing dose *D* for operational amplifier LM358 and IS-OU2 (IS-OU2-1 – the first sample and IS-OU2-2 – second sample) and LM358

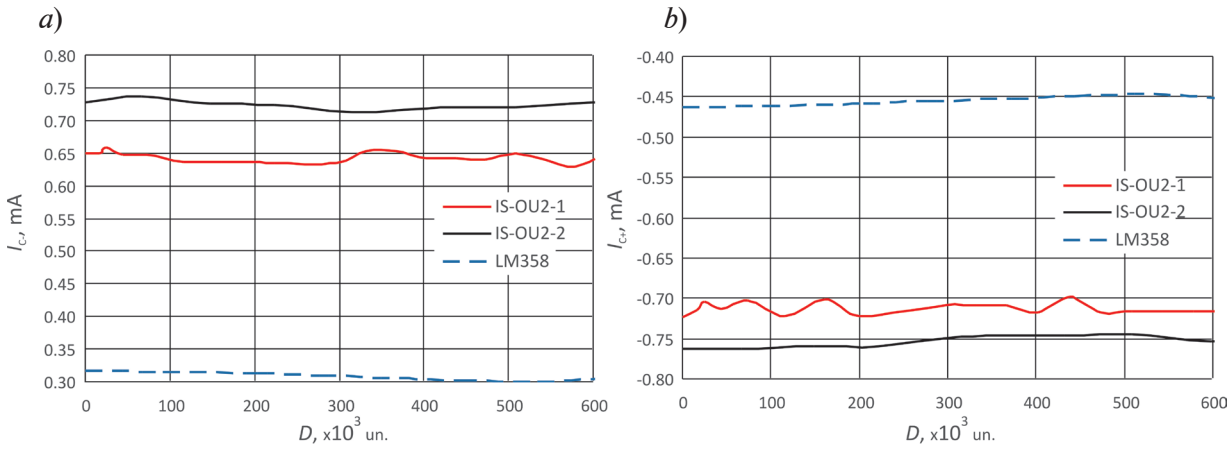

Fig. 2. Dependence consumption current I_C of the negative (*a*) and positive (*b*) polarity on the total ionizing dose *D* for operational amplifier IS-OU2 (IS-OU2-1 – the first sample and IS-OU2-2 – second sample) and LM358

Figure 2 shows the results of the radiation study of the consumption current I_C of negative (Fig. 2, *a*) and positive (Fig. 2, *b*) polarity of operational amplifiers for 2 samples of IS-OU2 (IS-OU2-1 – the first sample and IS-OU2-2 – second sample) and its analogue – LM358.

The consumption currents for the developed operational amplifier IS-OU2 and the analogue LM321 change very insignificantly with an increase in the total ionizing radiation dose.

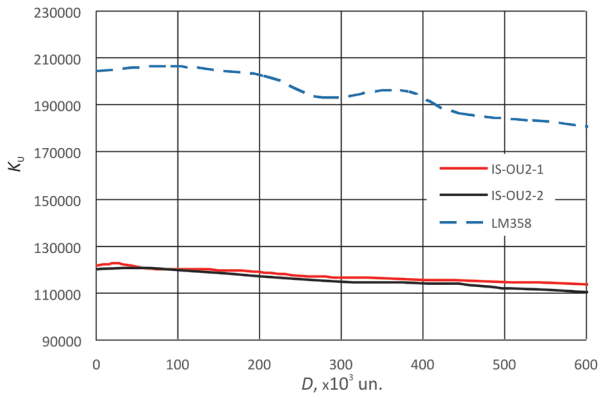

Fig. 3. Dependence of voltage gain K_U on the total ionizing dose *D* for operational amplifier IS-OU2 (IS-OU2-1 – the first sample and IS-OU2-2 – the second sample) and LM358

At the same time, the values of the consumption currents of negative and positive polarity for the developed operational amplifier IS-OU2 are quite comparable in order of magnitude with the analogue LM358. Figure 3 shows the dependences of the gain K_U on the total ionizing radiation dose D for the operational amplifier IS-OU2 and its foreign analogue LM358. It is evident that the gain does not decrease significantly with increasing total ionizing radiation dose. At the same time, the values of the gain for the developed operational amplifier IS-OU2, although somewhat smaller, are quite comparable in order of magnitude with the analogue LM358. Thus, the operational amplifier IS-OU2 samples and its foreign analogue LM358 in studied radiation exposure interval ($0-600\times10^3$ un.) do not undergone a functional failure and demonstrate radiation hardness to the effects of the total ionizing dose by studied parameters (input offset voltage, consumption current, voltage gain) and therefore can operate under radiation conditions such as spice and others [2].

Conclusion

The experimental study of the radiation hardness of the integrated circuit of the operational amplifiers IS-OU2 and analogue LM358 has been performed using X-ray research complex. Based on the results of experimental studies the radiation-sensitive parameters (input offset voltage, consumption current, voltage gain) have been found. It is established that operational amplifier IS-OU2 samples and its foreign analogue LM358 in investigated radiation exposure interval preserves a functional state without functional failure and demonstrate radiation hardness to the effects of the total ionizing dose by studied parameters. Because of this, the measured characteristics for the samples of the designed operational amplifiers IS-OU2 and analogue LM358 are quite close. Therefore, with taking into account, the designed and developed IS-OU2 operational amplifier demonstrates radiation hardness and can operate under radiation conditions and can be used for producing of devices in spacecraft electronics.

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